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DENVER, COLORADO, SEWAGE TREATMENT PLANT STUDY

Environmental Health Center
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DENVER, COLORADO, SEWAGE TREATMENT PLANT STUDY

Summary

The Denver sewage treatment plant, as studied, was principally a primary plant with facilities added for the return of raw sludge from the primary settling tanks and aeration of the mixture of return sludge and raw sewage. This method was developed by Mr. C. P. Gunson, plant superintendent, and is referred to as the "Gunson Process."

The plant design was based on an average flow of 54 m.g.d. from a contributing population of 317,000. During the period of this study (Jan. 16 - March 31, 1950) the average flow was 56.2 m.g.d.; the maximum and minimum flows were 92.0 and 22.0 m.g.d., respectively. The flow was composed of sanitary sewage from a connected population of about 425,000 and approximately 4 m.g.d. of meat packing plant wastes.

The Gunson process employs two units, a "sludge box" and an aeration tank, in addition to the conventional primary treatment facilities. The sludge box is located adjacent to the head of the aeration unit to permit the discharge of return primary sludge near the inlet of the aeration tank. The sludge in the box, during the period Jan. 16 - Feb. 17, 1950, was agitated by means of air jets, but these were later replaced by motor-driven paddles. For presentation and discussion, the study is divided into two periods designated Period 1 and Period 2. From Jan. 16 to Feb. 17 (Period 1) sludge was returned at the rate of 200 g.p.m., and for the period Feb. 17 to March 31 (Period 2) at the rate of 400 g.p.m. The sludge box provides a retention period of about 1 hour for the return of sludge at the rate of 200 g.p.m.

The mixture of raw sewage and return sludge passes through an aeration unit prior to reaching the primary clarifiers. This aeration unit provides a 15 min. detention period based on design flow of 54 m.g.d. However, due to an unsatisfactory control feature, the exact amount of sewage that was mixed and aerated with the return sludge could not be determined. During the period Jan. 16 - Feb. 23, the sluice gate (See Fig. 1) in the main plant flume used to divert sewage flow through the aeration unit was operated so that during the day little sewage passed through this unit and during the night almost the entire sewage flow was aerated. From Feb. 28 to March 31, control of the sluice gate was established so as to divert approximately half of the daily flow through the aeration unit.

Laboratory determinations, made on 12-hour composite samples of the plant influent, show the weighted average 5-day B.O.D. and suspended

solids content of the raw sewage as 227 p.p.m. and 201 p.p.m., respectively. This would give a population equivalent of the raw sewage, based on 0.167 lbs. B.O.D. and 0.2 lbs. suspended solids per capita per day, of 638,000 and 471,000, respectively. Plant effluent results show that the average B.O.D. and suspended solids content of the treated sewage were 162 p.p.m and 80 p.p.m., respectively. Thus the population equivalent discharged to the South Platte River from this plant, based on B.O.D., was 455,000,and 188,000 based on suspended solids. The average over-all plant efficiency, as measured by B.O.D. removal, is 29%, and as measured by suspended solids removal, is 60%.

During the period of air jet mixing (Period 1, Jan. 16 - Feb. 17) 53% of the samples run on return sludge prior to mixing with raw sewage, contained dissolved oxygen, whereas only 38% of the samples run during mechanical mixing (Period 2) contained dissolved oxygen. Analyses of the B.O.D. data, day and night composited samples, showed that the B.O.D. removal of the night samples was 34% for Period 1 and only 16% for Period 2. B.O.D. of the night raw sewage was 166 and 167 p.p.m., respectively. The B.O.D. of the daily raw sewage averaged 295 and 294 p.p.m. for Periods 1 and 2, and the reduction average was 37 and 32 per cent. The average dissolved oxygen content of the raw sewage was 1.65 p.p.m.; settled sewage, 0.90 p.p.m.; and the final effluent, 1.87 p.p.m. Similarly, dissolved oxygen results at the inlet and outlet of the aeration tank showed that a relatively constant oxygen level was maintained in the tank. During the period Feb. 23 - March 31, the average dissolved oxygen content at the inlet and outlet of the aeration unit was 1.16 and 0.97 p.p.m., respectively.

Solids determinations were made on samples of the return sludge at the inlet and outlet of the sludge box and of the mixed sludge and sewage at the inlet and outlet of the aeration tank. These studies showed that the solids concentration and characteristics remained relatively constant. The average total and suspended solids for the period Feb. 28 - March 31, in the mixture of raw sewage and return sludge before aeration, were 1060 p.p.m. and 432 p.p.m. and, after aeration, 1100 and 463 p.p.m.

Summary of B.O.D. and Suspended Solids Data

Period 1 and 2 (Jan.16 - March 31)
(Weighted for Flow)

	B.O.D. (p.p.m.)			Suspended Solids (p.p.m.)		
	Raw	Final	Per Cent Reduction	Raw	Final	Per Cent Reduction
Average	227	162	29	201	80	60
Population Equivalent	633,000	455,000		471,000	188,000	
			D a y			
Period 1	295	187	37			
Period 2	294	203	32			
			N i g h t			
Period 1	166	109	34			
Period 2	167	140	16			

Nitrites, nitrates, and ammonia together with total nitrogen were determined on companion samples of the raw sewage and final plant effluent for the purpose of observing any change brought about by the treatment process. No significant change was found in the ammonia, nitrite or nitrate content.

Coliform bacteria reduction, on the average, was high. A chlorine residual of 0.1 p.p.m. or greater in the effluent was found to give a high reduction. However, variability in chlorine application caused coliform bacteria in the effluent to range from a low of 3.6 up to 24,000,000 per 100 ml. A chlorine residual was found in 44 out of 52 samples.

Because of the sparse growth of zoogloea and the lack of any marked reduction in microscopically visible bacteria in passage of the sludge-sewage mixture through the aeration unit, it may be concluded that little biological change was brought about by the aeration process.

Conclusions

1. Operation of the Gunson process of return primary sludge in conjunction with the primary treatment process used at Denver during the period of study (Jan. 16 - March 31, 1950) showed an average overall plant efficiency of 29% and 60% as measured by B.O.D. and suspended solids removal, respectively.

2. The return of aerated, primary sludge may have had some beneficial effect in B.O.D. and suspended solids reduction for weak raw sewage in the range of 110 to 220 p.p.m. B.O.D.

3. Coliform bacteria reductions were relatively high; however, due to chlorination control and supply difficulties results were highly variable.

4. There was little biological change brought about by the aeration process.

5. The merits of the return sludge process may be more apparent under experimental conditions involving better control of the sewage flow through the aeration unit.

DENVER SEWAGE TREATMENT PLANT STUDY

Introduction

Since 1940, experiments have been under way at the Denver sewage treatment plant involving a process of returned primary sludge and aeration of the mixture of raw sewage and primary sludge as a means of increasing the over-all plant efficiency. This process is an adjunct to the plant which is operated as a primary treatment plant. Mr. C. P. Gunson, plant superintendent, who developed the technique referred to as the "Gunson Process," has reported* the results of the experiments for the period March, 1940, to May, 1946.

This study was prompted by the fact that a comprehensive water pollution investigation was under way in the South Platte River Basin. Denver is the largest municipality in this basin.

The study of the Denver sewage treatment plant was begun in mid-January, 1950, and continued until the end of March, 1950. The purpose of this study was to measure the efficiency of the Denver plant and to evaluate the benefits of the return of primary sludge with aeration.

Field operations on this project involved the use of two trailer laboratory units. The following personnel participated in this investigation.

Public Health Service:
- C. T. Carnahan, Public Health Engineer
- Paul Agnano, Sanitary Engineer (R)
- G. N. McDermott, Assistant Sanitary Engineer
- J. M. Cohen, Chemist
- Wm. R. VanNattan, Bacteriologist
- 1 Laboratory Aid and 1 Sample Collector

City and County of Denver:
- C. P. Gunson, Superintendent, Sewage Treatment Plant
- C. A. Davis, City Sanitary Engineer**

---

* C. P. Gunson, "Premerated Raw Sludge Recirculated Increased Primary Sedimentation Efficiency at Denver, Sewage Works Journal, 18, 1121, Nov., 1946).

** Deceased.

General Description

The 1940 U. S. Census population of Denver was 322,412. War-connected activity brought into the area a great number of military personnel and industrial workers. A large portion of this wartime influx has remained, resulting in an increase in population to more than 400,000. During the summer months, thousands of transients and vacationers impose a further load on the sewage facilities of Denver. The largest single industry producing industrial wastes of any significance is the slaughterhouse and meat packing industry.

The largest part of the Denver area may be classified as residential, and the majority of the permanent population is gainfully employed in commercial, sales and service enterprises.

Denver is sewered on the separate plan, and the sanitary sewer system, which comprises four separate districts, serves practically all of the developed property within the city limits, as well as some suburban property. It is estimated that approximately 400,000 persons are served by sewers. The sewage from this total contributing population is conveyed to two treatment plants. The small east side plant, not a part of this study, provides treatment for a contributing population of about 15,000.

Plant Description and Engineering Data

Plant Units

The Denver sewage treatment plant was placed in operation in December, 1937. Design was based on an average flow of 54 m.g.d., or 170 gallons per capita from a contributing population of 317,000. The plant was originally designed for primary treatment plus facilities for supplemental treatment by chemical precipitation and filtration through magnetite sand. The principal features of the original treatment works were as follows.

Screening, grit removal, preaeration and grease removal, coagulation with lime and ferric salts, sedimentation, filtration through magnetite sand, separate sludge digestion, and air drying of digested sludge on open beds.

Several changes in the original treatment process and modification and deletion of various units and equipment have been made since the construction of the plant. The units and equipment in operation during the study covered by this report were as follows:

(a) One Venturi meter, capacity 120 m.g.d., electrically connected to indicating and recording devices in the administration and chemical building.

(b) Three bar screens, 3/4" openings, equipped with mechanical cleaning equipment. Screenings are sorted to remove coarse material and hard objects, with the bulk of the screenings passed through three shredders and returned to the influent sewage.

(c) Two mechanically cleaned grit chambers. Grit from the chambers is conveyed to a loading platform by means of screw-type conveyors and loaded in trucks for disposal as fill.

(d) Aeration tank equipped for spiral-flow air diffusion. The tank is 140 feet long and has two compartments or passes, each 20 feet wide and 16 feet deep, giving a detention period of 15 minutes at the design flow of 54 m.g.d. Air is delivered through porous plates at the rate of 600 cu.ft./min. or, on the basis of design flow, 0.016 cu. ft. of air per gallon of sewage.

(e) Return sludge box 24 feet long, 14 feet wide and 4 feet deep, which provides a detention period of about 30 min. for return of sludge at the rate of 400 g.p.m. The sludge in the box was first agitated by means of air jets (Period 1) but this method was later replaced by motor-driven paddles (Period 2).

(f) Four Dorr clarifiers, each 140 feet in diameter. The basins provide a theoretical detention period of two hours and a settling rate of 877 gallons per sq. ft. per day, and have a weir length of 1759 ft. or 32.6 lineal feet per million gallons.

(g) Four manually controlled solution-feed chlorinators, each with a capacity of 2000 lbs. per day.

(h) Chlorine contact tank consisting of the original magnetite filter basin. Hydraulic features of the basin are conducive to short-circuiting. The estimated detention period in the basin is considered to vary from 5 to 15 minutes for the usual sewage flows through the plant.

(i) Four 55' diameter by 30' deep digesters with a combined capacity of 681,000 cu.ft. Three are equipped with floating covers,

while the fourth is fitted with an extension rim to provide a storage of 30,000 cu.ft. of gas. Temperature in the tanks is controlled by the circulation of hot water from boilers fired with sludge gas.

(j) Digested sludge is air-dried on 68 sand beds which provide a net area of 12.5 acres. Each bed is 80 x 100 ft. in plan.

Normal Operations

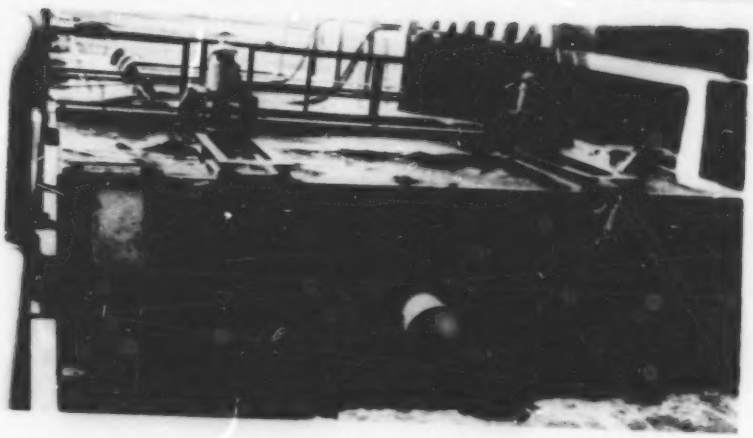
The raw sewage leaves the junction structure at the terminus of the sewer system and enters the plant through a Venturi meter, thence to the screen house where the flow is divided and carried in three 5-ft. channels. The screened sewage flows through a channel provided with longitudinal overflow weirs which automatically by-pass flows in excess of 90 m.g.d. The normal flow enters two grit removal chambers.

The split flow through the grit chamber is combined in the main plant flume leading to the settling basins. A motor-operated sluice gate in the flume (See Figure 1) diverts all or a portion of the sewage through the aeration tank. Sewage passing through the aeration tank re-enters the main plant flume and flows to a central distributing well which serves the four circular settling basins. The effluent from these basins is chlorinated and passed through a contact basin before discharge to the river.

A portion of the primary sludge is pumped to the return sludge box where it is aerated (Period 1) or mechanically agitated (Period 2) and returned to the raw sewage at the head of the aeration unit. The remaining sludge and skimmings from the settling basins are pumped to four sludge digesters. Supernatant liquor drawn from these digesters is normally returned to the influent raw sewage; however, during this study the supernatant was discharged to isolated sludge drying beds.

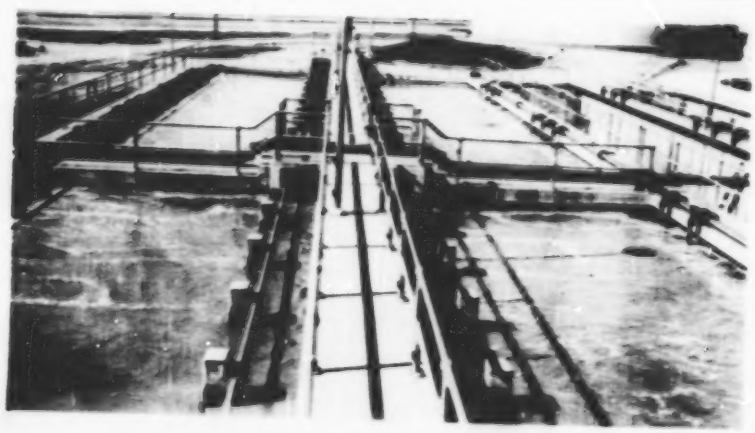
Digested sludge is air-dried on sand beds provided with an underdrain system. The drainage from the beds is returned to the influent raw sewage.

A plant flow diagram for normal operation is given in Figure 1.



SLUDGE RETURN BOX

Showing sludge inflow and discharge to aeration unit



AERATION TANK

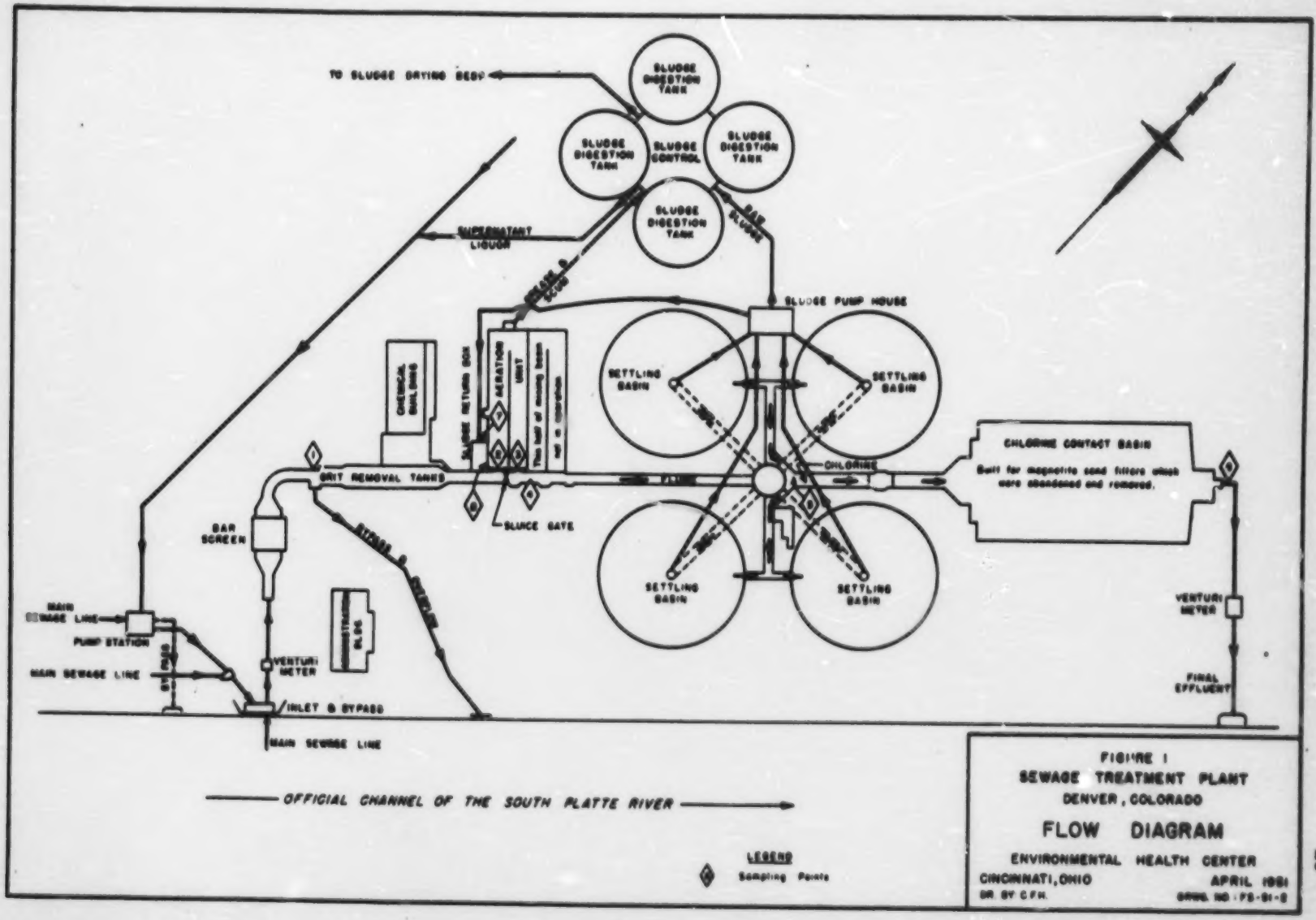


FIGURE 1
SEWAGE TREATMENT PLANT
DENVER, COLORADO

FLOW DIAGRAM

ENVIRONMENTAL HEALTH CENTER
CINCINNATI, OHIO — APRIL 1961
DR. BY C.F.H. — DRWG. NO. FS-61-8

Sewage Flow

Data from the Annual Plant Operating Report for 1949 show the average sewage flow was 56.7 million gallons per day. This flow was composed of sanitary sewage and industrial wastes originating principally from the meat packing plants. The average sewered population equivalent of the sewage entering the plant was reported to be 640,000. During the period of this study (January 16 - March 31, 1950) the average sewage flow was 56.2 m.g.d.; the maximum and minimum hourly flows were 92.0 and 22.0 m.g.d., respectively. Figures 2, 3, 4 and 5 illustrate various flow characteristics. Although the sewage collection system is a separate system, considerable volumes of surface drainage and infiltration enter the sewers and increase the normal flows.

Return Sludge Operation

During the first month of the study period, January 16 - February 17 (Period 1), primary sludge from 1 of 4 settling basins was returned to the raw sewage at the rate of 200 g.p.m., or 0.288 m.g.d. For the period February 18 to March 31 (Period 2), sludge from 2 basins (50%) was returned at the rate of 400 g.p.m. For the first month of operation (Period 1), return sludge was aerated and agitated in the sludge box by means of air jets. The agitation of the sludge was not sufficient to prevent the deposition of solids in the box and consequently a mechanical stirring device was installed in the box in lieu of the air jets for the remainder of the study (Period 2). The capacity of the box is such so as to provide a detention period of about 1 hour at a return sludge rate of 200 g.p.m.

Aeration Unit Operation

During the period January 16 to February 18, the sluice gate in the main plant flume used to divert the sewage flow through the aeration tank was opened wide at 10:00 A.M. and closed at 10:00 P.M. At night, when the gate was closed, all the sewage was mixed with return sludge and aerated within the aeration tank. During the day when the sluice gate was open (See Figure 1), little or no sewage was forced through the aeration unit.

From February 28 to March 31, control of the sluice gate was established so as to divert as much of the day sewage through the aeration tank as hydraulic conditions would permit. It is estimated that during the day sewage flows, approximately 30 m.g.d. of sewage were forced through the

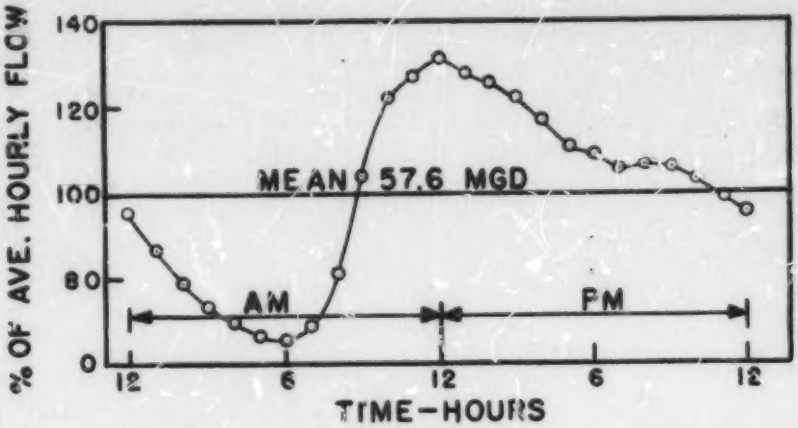


FIGURE 2
HOURLY VARIATION IN SEWAGE FLOW

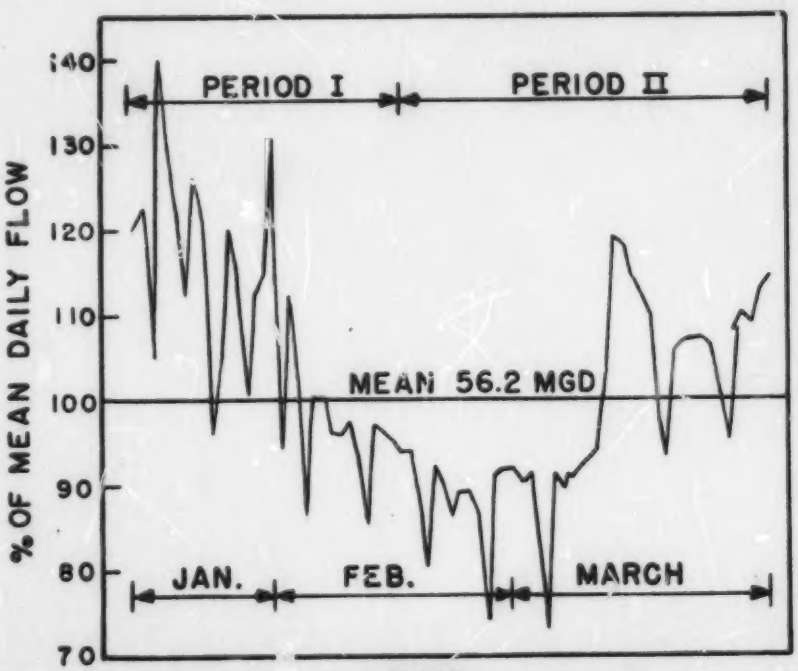


FIGURE 3
HYDROGRAPH OF DAILY SEWAGE FLOW

DRWG. NO.: FS-51-3

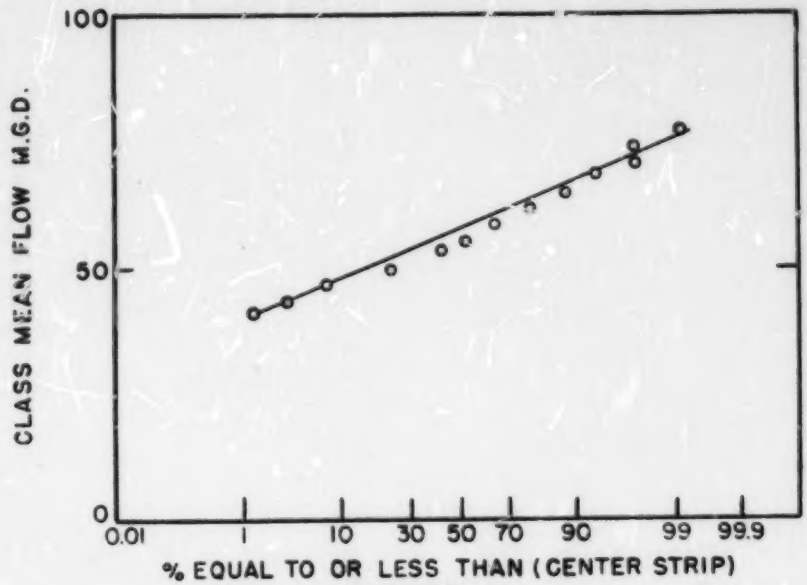


FIGURE 4

FREQUENCY OF DAILY FLOWS

(JAN. 16 — MARCH 31)

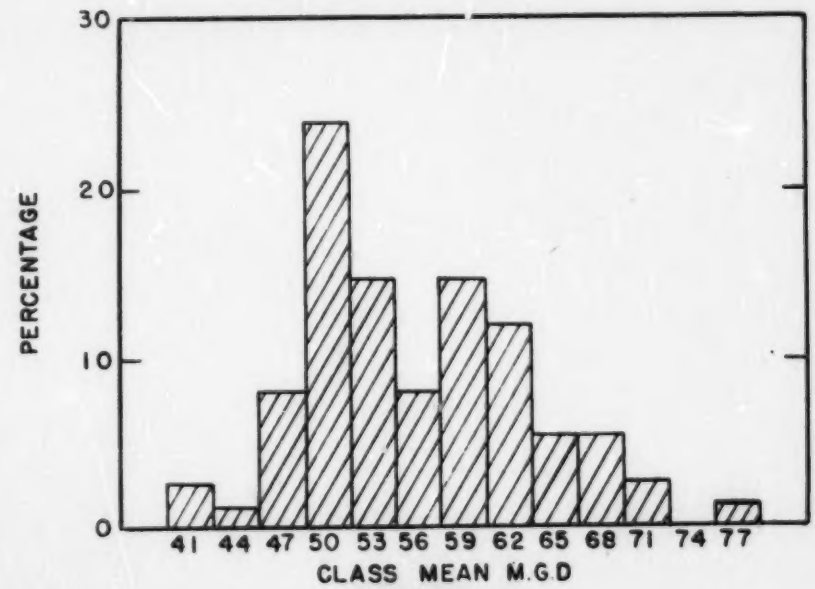


FIGURE 5

DISTRIBUTION OF DAILY FLOWS

(JAN. 16 — MARCH 31)

DRWG. NO.: FS-51-4

tank. The remainder was allowed to by-pass the tank and combine with the mixture of aerated sewage and sludge in the flume at the outlet from the aeration tank and passed directly to the settling basins.

Calculated detention time for the aeration of the mixture of raw sewage and return sludge in the aeration tank was 15 min. based on design flow of 54 m.g.d.

Air was delivered at a constant rate to the aeration tank from a single compressor unit with a rated capacity of 600 c.f.m. At a flow of 30 m.g.d. through the aeration tank, this would provide 0.029 cu.ft. of air per gallon of sewage.

Presentation of Data

Sampling and Analytical Methods

Over-all Plant Efficiency - For the purpose of measuring the over-all plant efficiency, samples were collected from the plant influent following the bar screens and shredders; from the settling basin effluent; and from the final effluent as discharged to the river. Samples of the raw and final sewage were collected primarily for biochemical oxygen demand and solids determination by means of commercial automatic proportional samplers. Twelve-hour composite samples of the raw and final sewage, to represent day and night operation, were collected in accordance with the following schedule:

Raw Influent
Day - from 9:00 AM to 10:00 PM
Night - from 10:00 PM to 9:00 AM

Final Effluent
Day - from 10:30 AM to 11:30 PM
Night - from 11:30 PM to 10:30 AM.

Allowance was made for flow time through the plant based on the average detention time computed from the flow data during December, 1949, and January, 1950, which was considered normal for the period of study. The average flow-through time used for the purposes of sampling was 1.5 hours. It should be noted, however, that this period is shorter during the day peak flows and is extended during the low night flows.

Sampling of the settling basin effluent was done by hand from the main plant flume leading to the chlorine contact tank. Hourly samples of one-pint portions were collected above the point of chlorine application and placed in refrigerated storage until composited in accordance with the flows recorded at time each sample was taken. Compositing periods were as follows:

Day - from 10:30 AM to 11:30 PM
Night - from 12:30 PM to 9:30 AM.

Samples for bacteriological analyses and dissolved oxygen determinations of the raw sewage, settled sewage, and final effluent were collected with a sampler which accommodated both dissolved oxygen and bacteriological sample bottles. Dissolved oxygen samples collected during night operations were dosed immediately following collection with 0.7 ml. sulfuric acid and 1.0 ml. sodium azide and stored until the following morning. Samples collected during the day were subjected to determination upon arrival at the laboratory.

Samples for bacteriological analyses of the chlorinated effluent were collected in specially marked bottles containing 40 mg. of sodium thiosulphate to neutralize any residual chlorine present in the sample. Samples collected during the night were stored at temperatures of 3 to 5° Centigrade until analyzed.

Gunson Process - To evaluate the operation of the process of return of primary sludge to the raw sewage as practiced at the Denver plant, samples were collected at the sludge return box and aeration tank units. The locations of the sampling points used during the study are shown on Figure 1.

Determinations were made on grab samples collected during the daylight hours from the following sampling points: (See Fig. 1 for locations)

(a) Return sludge box inlet (8)
(b) Return sludge box outlet (7)
(c) Mixed liquor (return sludge and raw sewage) near inlet of aeration tank (2)
(d) Mixed liquor (return sludge and raw sewage) at outlet of aeration tank.

1. Period 1. Jan.-Feb. - in main flume (4)
2. Period 2. Feb.-March 31 - in aeration tank (3)

To prevent any changes that would modify the character of the sludge and mixed liquor samples, sampling was scheduled during the daytime when the laboratory personnel were available for immediate analyses. Samples for oxygen utilization determination were aerated as completely as possible and the initial dissolved oxygen determined. The sample was then mixed by a slow speed mechanical stirring device, allowing a minimum of air entrainment, and then subject to dissolved oxygen determinations at intervals of 15 and 30 minutes for a period of several hours.

All other determinations were made in accordance with the procedures contained in Standard Methods for the Examination of Water and Sewage, 9th Edition, 1946.

In general, the program of sampling and laboratory work was developed to permit concentrated efforts on measures of plant efficiency and on the Gunson process operation on alternate weeks. During the periods when the primary efforts were directed toward the study of the Gunson process, daily B.O.D. determinations to measure plant efficiency were limited to samples of raw and settled sewage only.

Analytical Results

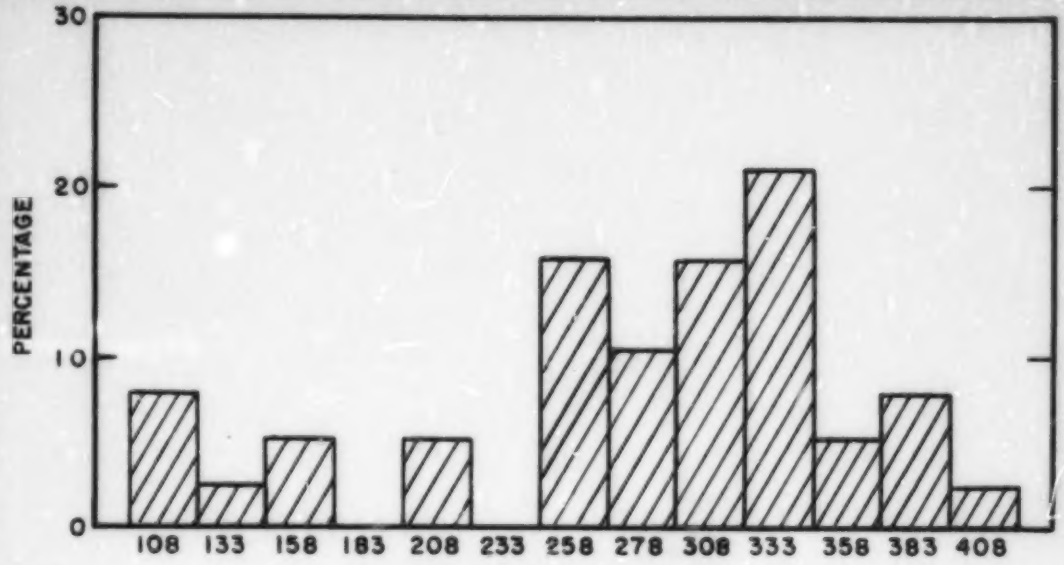
Plant Efficiency Study - As previously stated, samples were collected and analyzed to measure the over-all plant efficiency. Throughout the period of this study, the plant was operated on the Gunson process, that is, return of primary sludge and aeration. The basic analytical results obtained during the study are summarized in the tables that follow.

Standard 5-day 20°C. B.O.D. determinations were made on all samples for the purpose of measuring the over-all treatment plant efficiency. The average 5-day B.O.D. of the raw sewage for the entire period of study was 227 p.p.m., and varied from a minimum of 100 to a maximum of 313. The average B.O.D. of the final effluent was 162 p.p.m. This represented a reduction in B.O.D. of 29 per cent. B.O.D. results for the various periods of study are summarized in Table 1 and Figures 6, 7, 8 and 9.

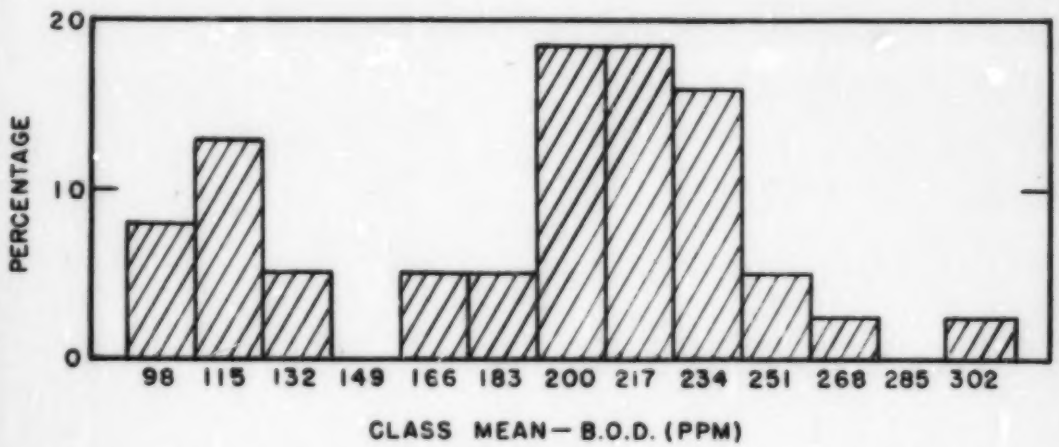
Table 1 - B.O.D. and Suspended Solids Results
(Results Weighted According to Flows)

	5-day B.O.D. (p.p.m.)			Suspended Solids (p.p.m.)		
	Raw Sewage	Plant Effluent	Per Cent Reduction	Raw Sewage	Plant Effluent	Per Cent Reduction
Period 1 (Jan.16 - Feb.17)						
Average	228	152	33	201	77	62
Median	241	152		206	76	
Maximum	313	220	53	245	106	76
Minimum	100	102	0	161	49	49
Standard deviation	54.3	32.7		30.0	17.2	
Period 2 (Feb.18 - March 31)						
Average	226	170	25	201	82	59
Median	256	161		206	69	
Maximum	291	245	35	276	133	74
Minimum	104	90	0	105	40	38
Standard Deviation	61.3	43.6		46.1	32.3	
Period 1 and 2 (Jan.16 - March 31)						
Average	227	162	29	201	80	60
Median	244	170		207	74	
Maximum	313	245	53	276	133	76
Minimum	100	90	0	105	40	38
Standard deviation	57.5	39.7		38.4	26.7	
Day (9 A.M. - 10 P.M.)						
Average*						
Period 1	295	187	37	248	88	65
Period 2	294	203	32	258	88	66
Night (10 P.M. - 9 A.M.)						
Average*						
Period 1	166	109	34	138	63	54
Period 2	167	140	16	122	73	40

* Samples with less than 107 p.p.m. B.O.D. in the raw sewage not included in summary of data.



RAW SEWAGE



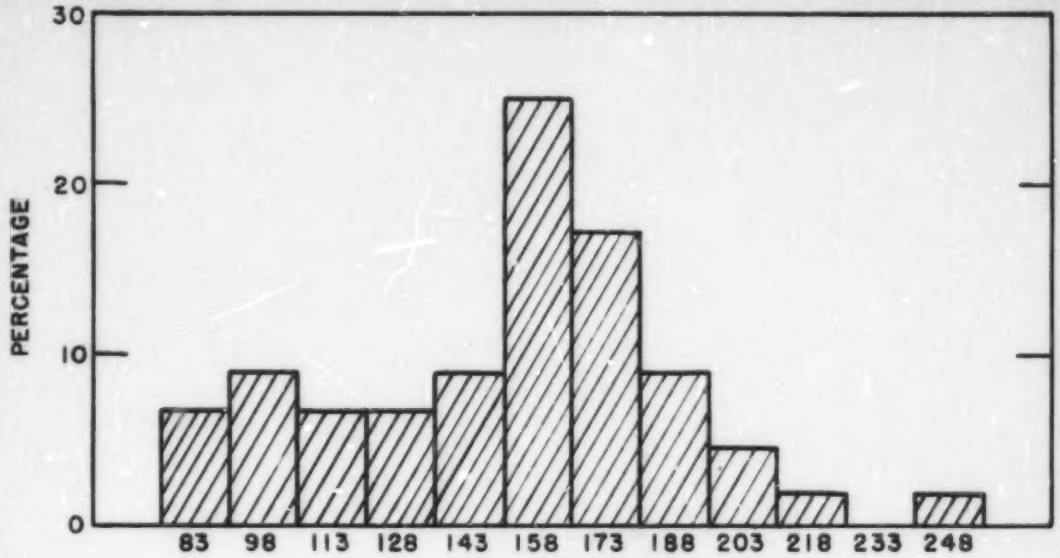
FINAL EFFLUENT

FIGURE 6

PERCENT DISTRIBUTION OF B.O.D.

DAY FLOW

DRWG. NO.: FS-51-5



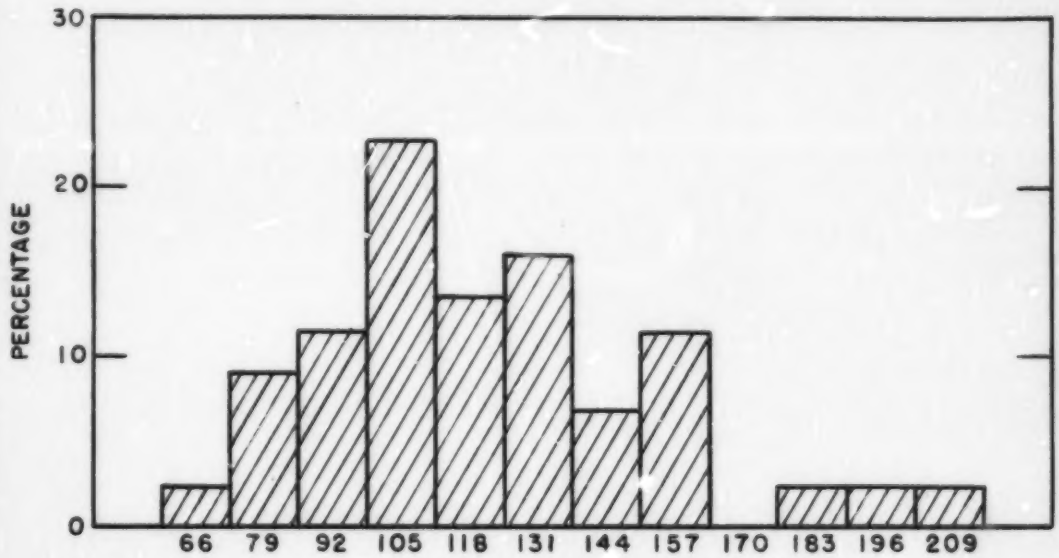


FIGURE 7

PERCENT DISTRIBUTION OF B.O.D.

NIGHT FLOW

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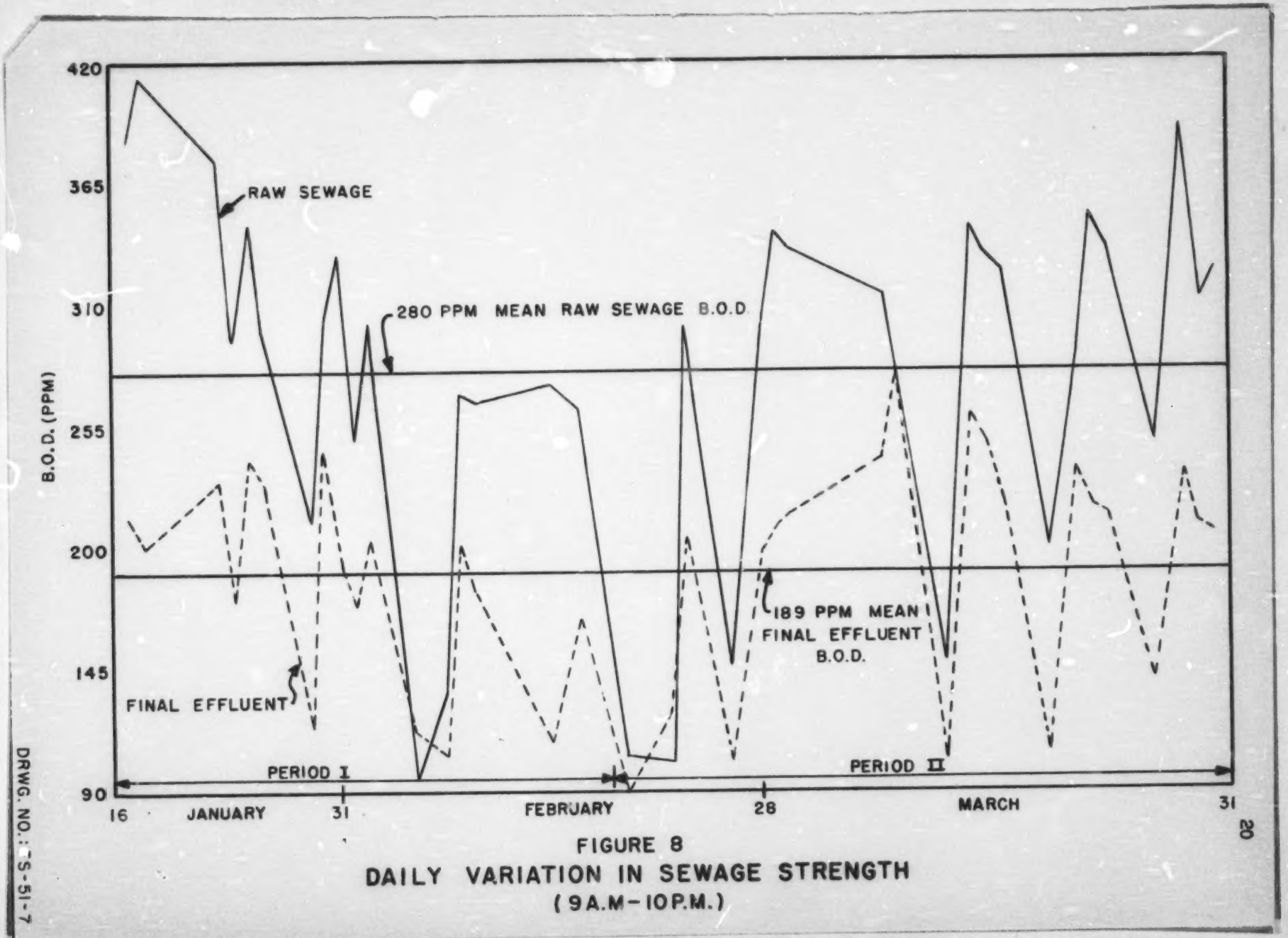
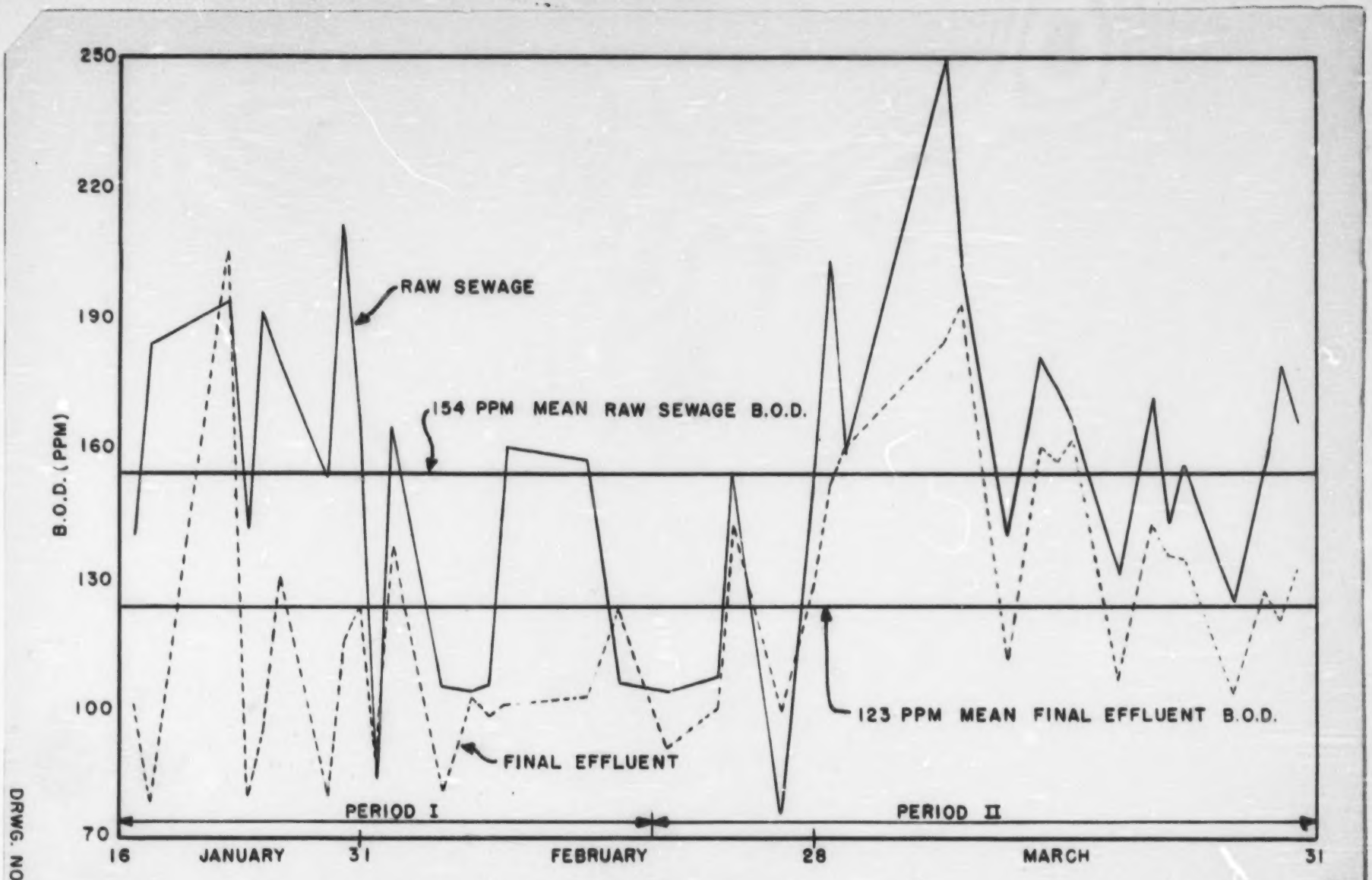


FIGURE 8

DAILY VARIATION IN SEWAGE STRENGTH

(9A.M-10P.M.)



DRWG. NO.:FS-51-8

FIGURE 9

NIGHTLY VARIATION IN SEWAGE STRENGTH

(10 P.M.– 9 A.M.)

Solids determinations were made on composite samples of the raw sewage and final effluent collected daily on alternate weeks during the plant efficiency study and on the settled sewage during the first week. These latter analyses were discontinued in order to permit a concentration of laboratory effort on more significant determinations. Determinations made on all samples included:

(1) Total solids, fixed and volatile
(2) Suspended solids, fixed and volatile
(3) Dissolved solids, fixed and volatile (by difference)
(4) Settleable solids.

A summary of the results of these analyses for the various periods of study is shown on Table 2. The weighted average suspended solids value of the raw sewage and final effluent for the entire period of study was 201 p.p.m. and 80 p.p.m., respectively, corresponding to 60 per cent removal. The average dissolved solids values for the entire period of the raw sewage and plant effluent were 613 p.p.m. and 623 p.p.m., respectively.

Table 2 - Solids Determinations*
(All results in p.p.m.)

	Total			Suspended			Dissolved			Settle-able
	Tot	Vol	Fix	Tot	Vol	Fix	Tot	Vol	Fix	
Raw Sewage										
Period 1 - Jan.16 - Feb.17										
Average	804	325	479	188	167	21	619	170	449	4.0
Maximum	976	443	564	201	261	62	722	414	555	-
Minimum	566	169	376	17	72	0	479	75	199	-
Period 2 - Feb.18 - March 31										
Average	798	301	497	188	156	32	610	145	465	4.0
Maximum	1085	508	587	356	298	88	813	256	557	6.0
Minimum	600	190	402	59	39	0	489	96	380	2.0
Period 1 and 2 - Jan.16 - March 31										
Average	801	312	489	158	161	27	613	156	457	4.0
Maximum	1085	508	587	356	298	88	813	414	557	6.0
Minimum	566	169	376	59	39	0	479	75	199	2.0
Final Effluent										
Period 1 - Jan.16 - Feb.17										
Average	688	228	460	77	69	8	584	146	438	0.25
Maximum	881	346	547	130	124	22	735	236	518	0.4
Minimum	527	135	325	37	32	0	461	83	313	0.1
Period 2 - Feb.18 - March 31										
Average	713	223	490	83	68	15	626	155	471	0.05
Maximum	872	324	584	137	114	38	762	223	555	0.1
Minimum	561	125	383	36	30	1	446	92	365	0.0
Period 1 and 2 - Jan.16 - March 31										
Average	702	226	476	79	68	11	623	158	465	0.15
Maximum	881	346	584	137	124	38	762	236	555	0.4
Minimum	527	125	325	36	30	0	446	83	313	0.0

* Summary of data not weighted for flow variation.

Residual chlorine was determined on all samples of the chlorinated effluent. Out of the 82 samples tested for chlorine residual, 44 were found to have no measurable residual.

Examinations for the presence of coliform organisms were made on samples of the raw sewage, settled sewage, and final plant effluent collected daily on alternate weeks during the course of the study. Samples collected from the chlorinated effluent were treated with sodium thiosulphate to neutralize any residual chlorine present before examination. The results of the standard confirmed test are reported as most probable number (MPN) of coliform per 100 ml. and are summarized in Table 3 and Figure 10.

The median, maximum, and minimum pH values, compiled from determination on all composite and grab samples collected during the study are also included in Table 3. These data indicate no significant change in pH value as the sewage passes through the plant.

Table 3 - Bacteriological and pH Results

	Coliforms (MPN/100 ml.)			pH				
	Grab Samples			Grab Samples			12-hour Composite	
	Raw Sewage	Settled Sewage	Final Effluent	Raw Sewage	Settled Sewage	Final Effluent	Raw Sewage	Final Effluent
Period 1 and 2 - Jan.16 - March 31								
Median	15,000,000	15,000,000	69,000	7.6	7.5	7.5	7.5	7.5
Maximum	93,000,000	43,000,000	24,000,000	9.6	8.1	8.1	7.8	7.9
Minimum	1,500,000	4,300,000	3.6	7.2	7.3	7.3	7.1	7.2

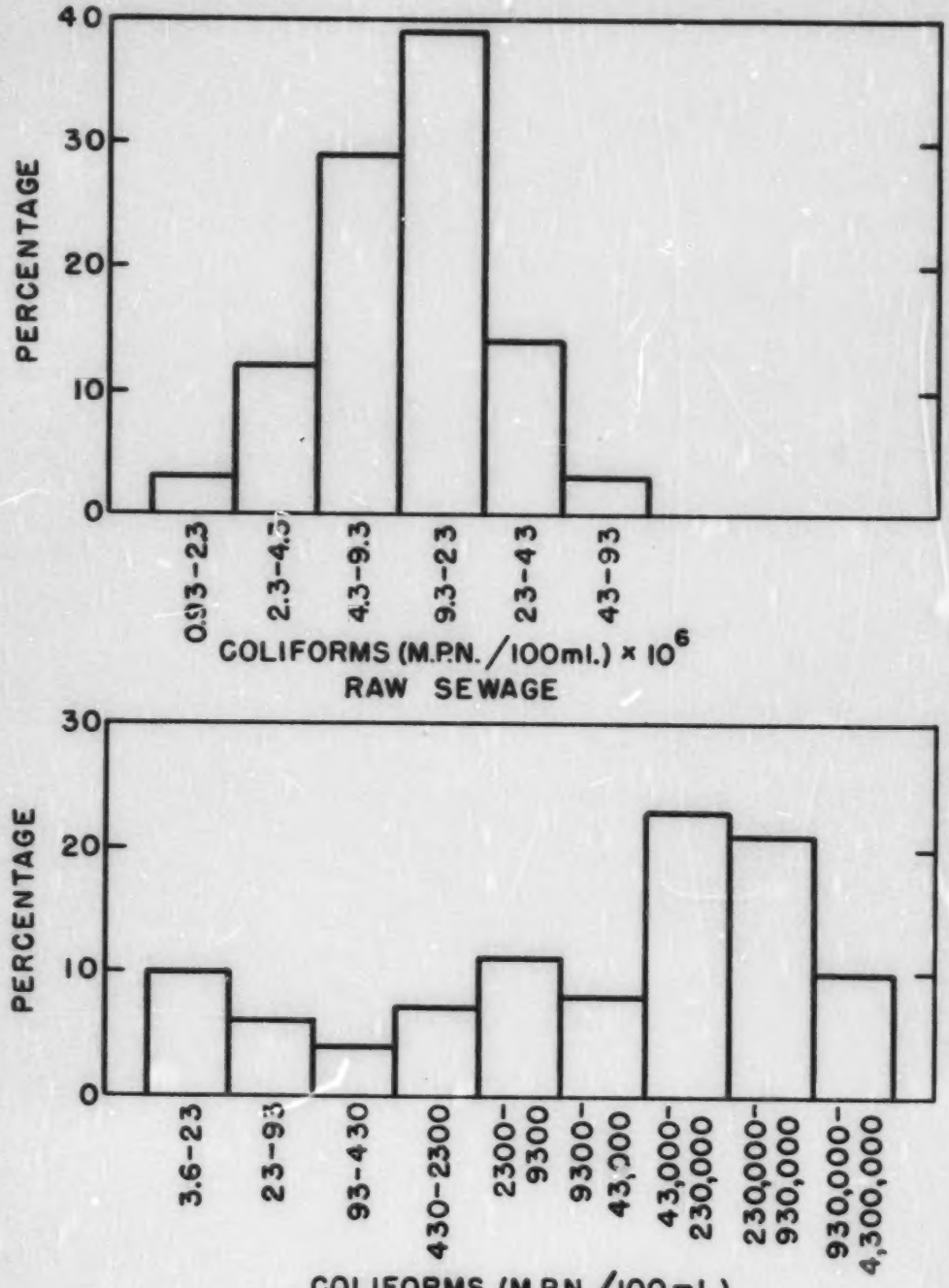
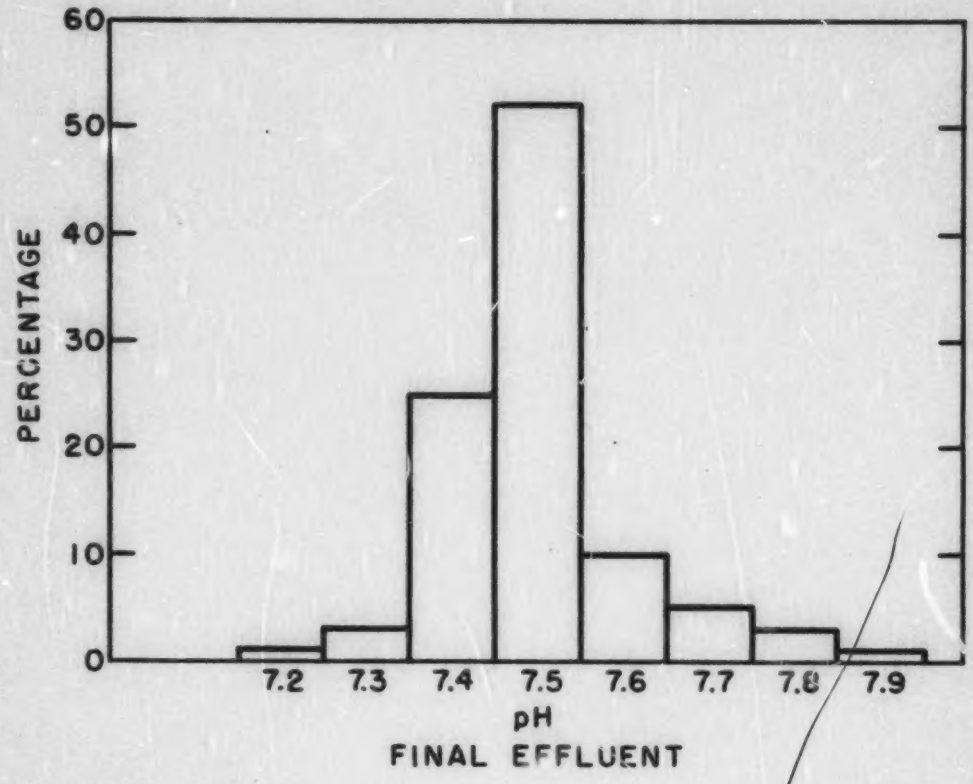


FIGURE 10
DISTRIBUTION OF COLIFORM BACTERIA
(JAN. 16 - MARCH 31)

DRWG. NO.: FS-51-9



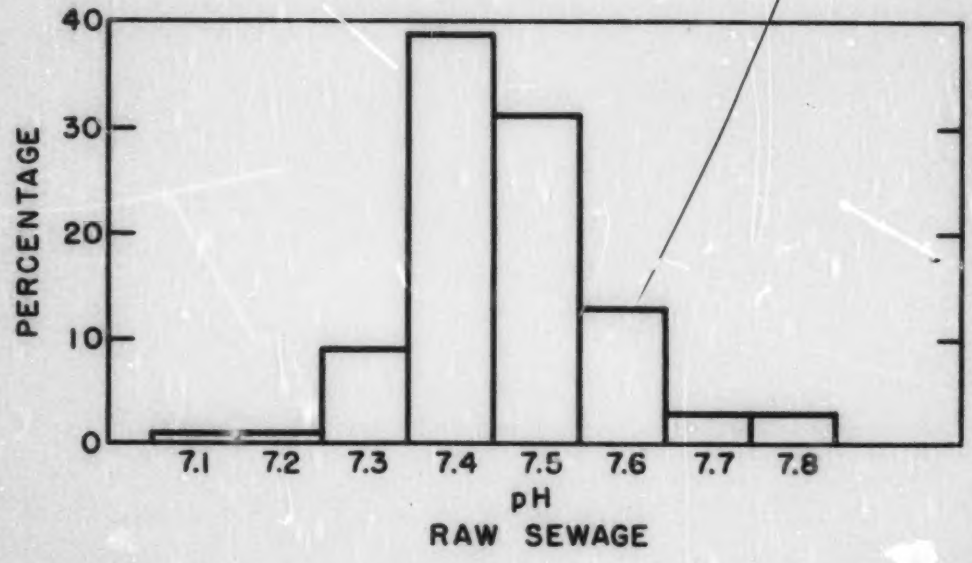


FIGURE 11
PERCENT DISTRIBUTION OF pH
(12 HR. COMPOSITE SAMPLES)

DRWG. NO.: FS-51-10

Dissolved oxygen was determined on grab samples of the raw sewage, settled sewage and final plant effluent during the over-all efficiency studies to observe the effects of the aeration process in maintaining aerobic conditions in the sewage as it passes through the plant. The results are shown on Table 4.

Table 4 - Dissolved Oxygen Results

	Raw Sewage		Settled Sewage		Final Effluent	
	Temp. °C.	D.O. ppm	Temp. °C.	D.O. ppm	Temp. °C.	D.O. ppm
Period 1 - Jan.16 - Feb .17						
Average	14.1	1.94	14.1	1.05	13.6	1.91
Maximum	16.5	5.01	18.0	2.35	16.5	4.35
Minimum	11.0	0.00	11.5	0.00	12.0	0.00
Period 2 - Feb.18 - March 31						
Average	14.6	1.29	14.1	0.73	14.2	1.82
Maximum	16.5	4.43	16.0	3.98	15.5	3.65
Minimum	11.0	0.00	11.0	0.00	11.0	0.00
Period 1 and 2 - Jan.16 - March 31						
Average	14.4	1.65	14.1	0.90	13.8	1.87
Maximum	16.3	5.01	18.0	3.98	16.5	4.35
Minimum	11.0	0.00	11.0	0.00	11.0	0.00

Total organic nitrogen was determined on samples of the raw sewage on alternate weeks during the plant efficiency study for the purpose of defining sewage characteristics.

Nitrite, nitrate and ammonia together with total nitrogen were determined on companion samples of the raw sewage and final plant effluent for the purpose of observing any change brought about through the treatment process. These results are summarized in Table 5. The organic nitrogen averaged 11.2 p.p.m. and 8.3 p.p.m. for the raw sewage and final effluent respectively, representing a 25 per cent removal. No significant change was found in the ammonia, nitrite or nitrate content.

Table 5 - Nitrogen Results

(All results in p.p.m.)

	Ammonia Nitrogen		Organic Nitrogen		Nitrite Nitrogen		Nitrate Nitrogen	
	Raw Sewage	Plant Effl.	Raw Sewage	Plant Effl.	Raw Sewage	Plant Effl.	Raw Sewage	Plant Effl.
				Jan.16 - March 31				
Average	16.3	17.1	11.2	8.3	0.65	1.0	0.23	0.23
Maximum	18.5	20.0	17.1	14.3	1.25	1.50	0.52	0.40
Minimum	11.0	15.0	6.0	3.0	0.35	0.48	0.00	0.00

Gunson Process - On alternate weeks, samples were collected and analysed to determine the changes brought about in the solids characteristics, dissolved oxygen, and biological organisms due to the operation of the Gunson process. The basic analytical results are summarized in the tables that follow.

Dissolved oxygen determinations were made on the return sludge as discharged into the aeration tank and on the mixture of raw sewage and return sludge at both the inlet and outlet of the aeration unit. During the period of air jet mixing of return sludge (January 16 - February 17), 53 per cent of the samples of return sludge contained a measurable D.O., which averaged 1.24 p.p.m.; whereas during the period of mechanical mixing of return sludge, only 38 per cent of the samples contained D.O., which averaged 0.84 p.p.m.

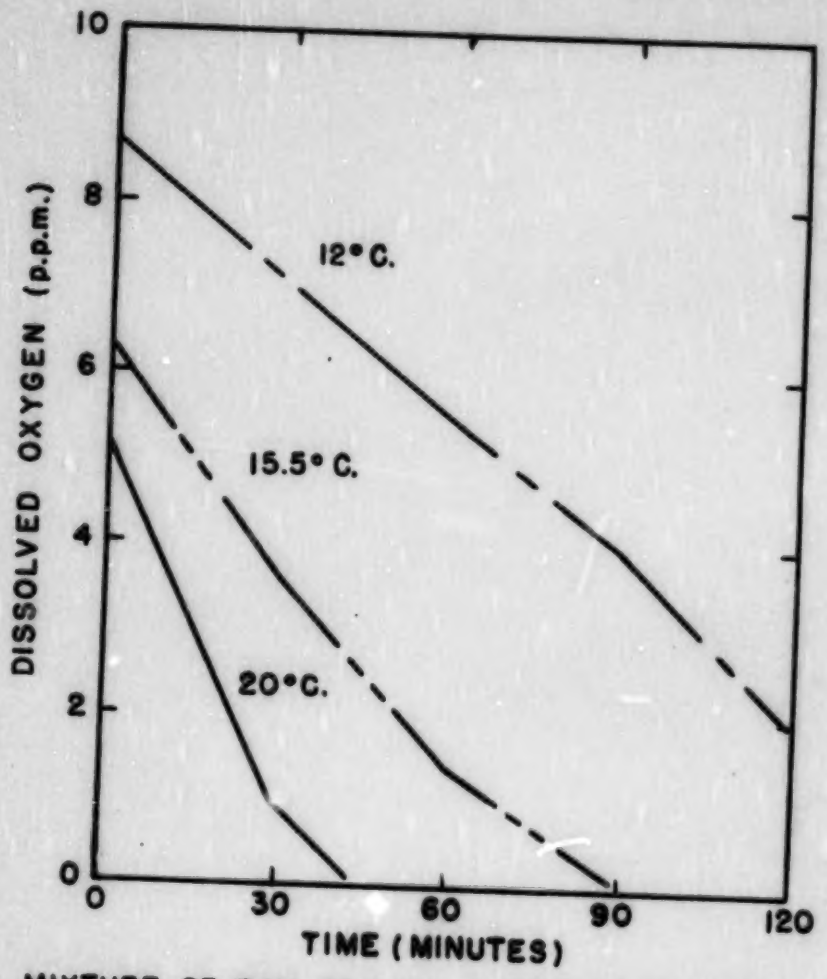
Results of the dissolved oxygen analyses made on the aeration unit are summarized in Table 6. During the periods January 16 - February 17 and February 17-28, samples were collected downstream from the aeration unit and contained a mixture of the by-passed sewage and mixture of sewage and sludge after passing through the aeration unit. For the period February 29 - March 31, samples were collected within the aeration unit prior to discharging into the main flume.

Table 6 - Dissolved Oxygen Data - Guasea Process

	Raw Sewage		Mixture of Raw Sewage and Return Sludge			
			Inlet of Aeration Unit		Main Flume Below Aeration Unit	
	Temp.	D.O. ppm	Temp.	D.O. ppm	Temp.	D.O. ppm
Jan.16 - Feb.17						
Average	14.1	1.94	14.9	1.58	15.0	1.57
Maximum	16.5	5.01	16.0	2.28	16.0	2.10
Minimum	11.0	0.00	14.0	0.92	13.5	1.06
Feb.18 - Feb.28						
Average	14.6	1.25	14.7	0.93	14.7	1.61
Maximum	15.5	3.72	15.0	1.75	15.5	2.25
Minimum	12.0	0.20	14.0	0.37	13.5	1.10
Feb.29 - March 11 *						
Average	14.7	1.30	15.0	1.16	15.1	0.97
Maximum	16.5	4.43	15.5	1.60	16.0	1.50
Minimum	11.0	0.00	14.5	0.70	14.5	0.60

* Sample point changed from "Main Flume below Aeration Unit" to a point within the aeration unit. (See Sampling Points 3 & 4, Figure 1).

Oxygen utilization determinations were made on a limited number of samples of the mixture of sludge and raw sewage at the outlet and inlet of the aeration unit. These results are shown in Figure 12.



MIXTURE OF RAW SEWAGE & RETURN SLUDGE
(INLET OF AERATION UNIT)

FIGURE 12

TYPICAL OXYGEN UTILIZATION CURVES

DRWG. NO.: FS-51-11

Solids determinations were made on the composite samples of raw sewage and final effluent, and of the mixture of sludge and sewage at the inlet of the aeration tank and again in the main flume below the outlet of the aeration tank. The results for the periods January 16 - February 17 (Period 1) and February 17-28 are shown on Table 7.

During Period 1, January 16 - February 17, raw sludge was being returned at the rate of 200 g.p.m. The average suspended solids in the raw sewage for this period was 188 p.p.m., and the average suspended solids in the mixture ahead of the inlet to the clarifier was 380 p.p.m. The return of sludge for the first part of Period 2, February 17-28, was 400 g.p.m., and the average suspended solids of the raw sewage for this portion of the period was 142 p.p.m., and of the mixture 414 p.p.m.

Table 7 - Suspended Solids Results - Guneon Process

(All results in p.p.m.)

	Raw Sewage	Mixture of Raw Sewage and Return Sludge		Final Effluent
		Inlet of Aeration Unit	Main Flume Below Aeration Unit	
		Jan.16 - Feb.17		
Average	188	447	380	77
Maximum	301	976	758	130
Minimum	77	164	138	37
		Feb.17 - Feb.28		
Average	142	519	414	46
Maximum	264	754	906	57
Minimum	59	168	174	36

For the period February 28 - March 31, the point of sampling below the aeration unit was changed from the main channel to a point within the aeration unit. All other sample points remained the same. This change allowed for an evaluation of the effects of the aeration unit on the solids characteristics of the mixture of return sludge and sewage. The results of these studies are shown in Table 8. The average total and suspended solids in the mixture of raw sewage and return sludge before aeration was 1060 p.p.m. and 432 p.p.m., and after aeration 1100 p.p.m. and 463 p.p.m.

Table 8 - Effect of Aeration Unit on Solids Characteristics

	Suspended Solids (p.p.m.)				Total Solids (p.p.m.)			
	Raw Sewage	Mixture of Raw Sewage and Return Sludge		Final Effluent	Raw Sewage	Mixture of Raw Sewage and Return Sludge		Final Effluent
		Inlet	Outlet			Inlet	Outlet	
	February 28 - March 31							
Average	197	432	463	88	812	1060	1100	723
Maximum	336	568	668	137	1085	1481	1640	872
Minimum	86	260	292	41	628	744	804	561

Solids determinations were made on samples of the return sludge at the inlet and outlet of the sludge box. The average results are shown in Table 9. The average solids concentration of the sludge pumped into the box during the first month was 19,500 p.p.m., and for the entire period of the test was 15,000 p.p.m. The solids concentration of the sludge as discharged from the mixing box was 15,500 p.p.m. for the first month, and 13,500 p.p.m. for the entire period of study.

Microscopic examinations for biological organisms were made on samples of the return sludge and on the mixture of return sludge and sewage at the inlet and outlet of the aeration tank. The results of these examinations are summarised as follows:

1. All samples including aerated sludge samples contained large numbers of minute bacteria other than the rod-shaped zoogleeal organisms. This is characteristic of raw sewage generally.

2. One bacterium, Spirillum sp., was found to increase in numbers from inlet to outlet of the aeration tank.

3. Zoogloea and Sphaerotilus sp. were present in all samples, but neither was abundant enough even to approach the concentrations found in activated sludge.

4. Few protozoans were found.

Table 9 - Solids Data Return Sludge

(All results in p.p.m.)

	Total Solids		Suspended Solids		Settleable Solids	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
January 16 - February 17						
Average	19,532	15,586		14,311		492
Maximum	52,045	27,956		26,360		750
Minimum	5,992	6,156		4,700		200
January 16 - March 31						
Average	14,969	13,485	11,423	12,192	425	434
Maximum	52,045	27,956	17,800	26,360	470	750
Minimum	5,708	4,231	6,584	4,700	380	200

Discussion

Plant Efficiency - Laboratory determinations made on the composited samples of the plant influent show the average 5-day B.O.D. and suspended solids content of the raw sewage was 227 p.p.m. and 201 p.p.m., respectively. Plant effluent results show the average B.O.D. and suspended solids content of the treated sewage was 162 p.p.m. and 80 p.p.m., respectively. This gives an over-all plant efficiency, as measured by B.O.D. removal, of 29 per cent; and 60 per cent as measured by suspended solids removal.

During the period of this study the average flow was 56.2 m.g.d., as compared to the design flow of 54 m.g.d., indicating a hydraulic overload of about 5 per cent. At a flow of 56.2 m.g.d., the settling basins provide a theoretical detention period of approximately 1.9 hours and an overflow rate of 920 g.p.d. per sq. ft. The weir loading of the settling units is 32,000 g.p.d. per lineal foot at average flow. The Denver plant, operated as a plain primary plant, might be expected to give an over-all average reduction in B.O.D. of from 30 to 35 per cent, and a suspended solids reduction of about 60 to 65 per cent.

During the time of this study, the operation of the Gunsen process of return sludge in conjunction with the primary treatment process gave no average over-all improvement over what might have been expected by primary treatment alone.

B.O.D. and Suspended Solids Analyses by Periods - B.O.D. reduction was extremely low when the strength of the raw sewage was less than about 100 p.p.m. During the entire period of study (January 16 - March 31), eleven composited 12-hour samples, approximately 15 per cent of the total, fell in this range. The average B.O.D. strength of these samples was 100 p.p.m., and the average B.O.D. reduction was 7 per cent. The reduction in B.O.D. of these samples appeared to be independent of time or period of sampling. For this reason, these samples have been excluded from the averages in the discussion that follows.

As stated previously, the study was divided into two periods. During Period 1 (January 16 - February 17), sludge was returned at the rate of 200 g.p.m. and agitated by air. For Period 2 (February 18 - March 31), sludge was returned at the rate of 400 g.p.m. and mechanically stirred. During Period 1, 53 per cent of the sludge samples at the outlet end of the sludge box contained measurable dissolved oxygen, whereas only 38 per cent of the samples collected during Period 2 contained dissolved oxygen.

Dividing the B.O.D. results into the 12-hour day and night composites showed that the B.O.D. removal of the night samples was 34 per cent for Period 1 and only 16 per cent for Period 2. Analysis of these data showed this difference to be statistically significant. The average B.O.D. of the raw sewage for Periods 1 and 2 was 166 p.p.m. and 167 p.p.m., respectively. The same difference in removal was not evident in the daily composited samples, where the raw sewage B.O.D. averaged 295 and 294 p.p.m. for Periods 1 and 2. The reduction for Period 1 was 37 per cent, and for Period 2, 32 per cent. This difference is not statistically significant. (See Table 1).

A similar division of the suspended solids analyses showed that during night operations the percentage removed for Period 1 was 54 per cent and for Period 2 only 40 per cent. This is also a statistically significant difference; however, this difference in per cent reduction may have been caused in part at least by lower suspended solids in the night sewage during Period 2. The suspended solids in the night raw sewage during these two periods averaged 138 p.p.m. and 122 p.p.m., respectively. The results of the day samples, however, showed no marked difference in removal between Periods 1 and 2. The average day raw sewage suspended solids averaged 248 and 258 for Periods 1 and 2. It is

therefore concluded that the return of aerated primary sludge has some beneficial effect on B.O.D. and suspended solids reduction for weak, raw sewage in the range of about 100 to 200 p.p.m. B.O.D.

Solids Determinations - Solids determinations on the raw sewage and final effluent indicated no significant change in the dissolved solids content of the sewage. Similar solids determinations made on the mixture of raw sewage and return sludge at the inlet and outlet of the aeration unit showed that no significant change in the solids characteristics of the mixture took place as the sewage passed through the aeration unit.

Studies made on the solids characteristics of the return sludge at the inlet and outlet of the sludge return box indicate no significant change in the sludge within the box.

Dissolved Oxygen - The oxygen content in samples taken from the raw sewage influent, settled sewage, and final effluent showed that there was no significant reduction in the oxygen content of the sewage as it passed through the plant. The calculated flow-through time for the average day flow of 67.4 m.g.d. was 1.58 hours, and for the average night flow of 47.7 m.g.d. was 2.24 hours.

The sampling stations for the period Feb. 28 - March 31 were located so as to evaluate the effects of the aeration unit on the D.O. content of the mixture of raw sewage and return sludge. This study indicated that a relatively constant oxygen level was maintained in the tank.

Oxygen Utilization - Oxygen utilization determinations made on the mixture of raw sewage and return sludge before aeration indicated a fairly rapid rate of utilization varying with the temperature of the mixture. This rate of utilization varied from 4.2 p.p.m. oxygen in 30 min. at 20°C. to 1.7 p.p.m. oxygen in 30 min. at 12°C. The rate of utilization of the mixture after aeration showed a slight decrease.

Bacteriological - Bacteriological examination for coliform bacteria reduction in the chlorinated plant effluent shows relatively high average reduction. High coliform reductions were found when a chlorine residual of (.1 p.p.m. or greater was present in the effluent. Because of chlorination control difficulties and chlorine supply failures, results were highly variable. Effluent coliform MPN concentrations ranged from a low of 3.6 to a high of 24,000,000 coliforms per 100 ml.